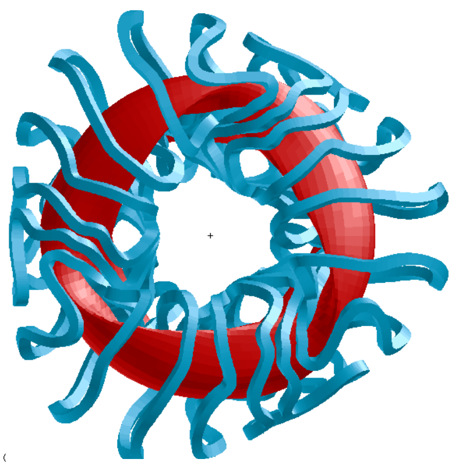
Fueling the Future

Design Optimization via Supercomputing ----- FUSION ENERGY SCIENCES

The rapid advances in supercomputing capabilities are clearly recognized as catalysts for scientific discovery and technological development in the twenty-first century. When applied to the design of highly complex systems, integrated computer simulation represents an exciting new application for advanced computation that can help solve some of the most challenging research and development problems in the Department of Energy Office of Science programs as well as industry. This is a powerful new tool that can cost-effectively accelerate progress in moving from basic research discoveries to practical prototypes and products. An excellent example in the Fusion Energy Sciences Program is the utilization of such capabilities to cost-effectively produce an attractive design for the National Compact Stellarator Experiment (NCSX), which will test ideas for significantly improving the magnetic confinement of high-temperature plasmas.

Complex systems, such as magnetically confined plasmas for fusion energy, are described by many variables and are governed by a large number of physical mechanisms and processes. Since construction and operation of experimental facilities to advance the requisite knowledge base can be slow and costly, new science-based design tools are needed to improve upon such "cut and try" methods. The key here is applying the integrated scientific simulation capabilities made possible by modern supercomputers for the design of experimental apparatus. In addition to efficiently combining important physics properties from comprehensive theoretical models, modern massively parallel computers allow the designer to conduct extensive campaigns of computer experiments on a huge number of designs in a short time and at low cost. Powerful optimization software is now used to systematically exercise all the variables and efficiently home in on the best designs for testing in real laboratory experiments.


Stellarator plasma with magnetic coils.

To provide the needed enhancements of the plasma confinement properties at the core of a fusion reactor, the search for the best shape has centered on axisymmetric toroids, of which the tokamak, whose shape can be completely described with only four variables, is the best known. More complex three-dimensional plasma toroids called stellarators, whose cross section shapes depend on where they are sliced, have key potential advantages for fusion power plants. These include efficient sustainability in steady state and being less prone to sudden plasma termination events. However, it takes about forty variables to describe the more complicated shapes of stellarators. Since design permutations to be explored accordingly approach nearly a million variations, quickly finding the most promising designs in such a large landscape is a formidable challenge in computational complexity. Enabled by modern supercomputing resources, integrated simulations, which combine physics models with practical engineering criteria, have come up with designs for "Compact Stellarators," a new fusion concept that synergistically combines the best features of tokamaks and stellarators.

After first identifying the most promising plasma shapes and then the magnetic field coil shapes needed to produce them, scientists and engineers at the Princeton Plasma Physics Laboratory and Oak Ridge National Laboratory have completed a feasible design for an NCSX to test the new concept. The manufacturability of the NCSX components has been confirmed by U.S. industrial suppliers, and the design was positively reviewed by a DOE panel in preparation for starting fabrication in 2003. Progress this rapid was possible only through the use of integrated simulation at every step of the design process. Compared to traditional approaches, which would have required a number of smaller and more narrowly focused experiments to reach a comparable stage, it has shortened the development time by about ten years with a savings of about $50-100M in research and development costs. This is an excellent example of how simulations, enabled by modern supercomputers, can provide an attractive, cost-effective new path for rapidly moving from innovative research discoveries to practical experiments and products of benefit to the DOE Office of Science programs as well as to industry.